1 Title: VISTA VARIABLES IN THE VIA LACTEA (VVV)

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1.1 Abstract:(10 lines max)

We propose a public IR variability survey of the entire Milky Way bulge. This would take 950 hours, covering $\sim 5 \times 10^8$ point sources within an area of about 360 sq deg, including 40 globular clusters and 114 open clusters. If there is no other Chilean proposal, the survey would be extended to 1750 hours for a total area of 600 sq deg. The final products will be a deep IR atlas of the bulge, and a catalog of $\sim 10^6$ variable point sources. These will allow to map the 3-D structure of the bulge (unlike single epoch surveys that only give 2-D maps) using well understood primary distance indicators such as RR Lyrae stars, and to obtain important information on the age of its population. The observations will be combined with data from MACHO, OGLE, VST, SPITZER, HST, CHANDRA, INTEGRAL, and ALMA for a complete understanding of the variable sources in the inner Milky Way. Several important implications for the history of the Milky Way, for globular cluster evolution, for the population census of the bulge and center, and for pulsation theory would follow from this survey.

2 Description of the survey: (Text: 3 pages, Figures: 2 pages)

2.1 Scientific rationale:

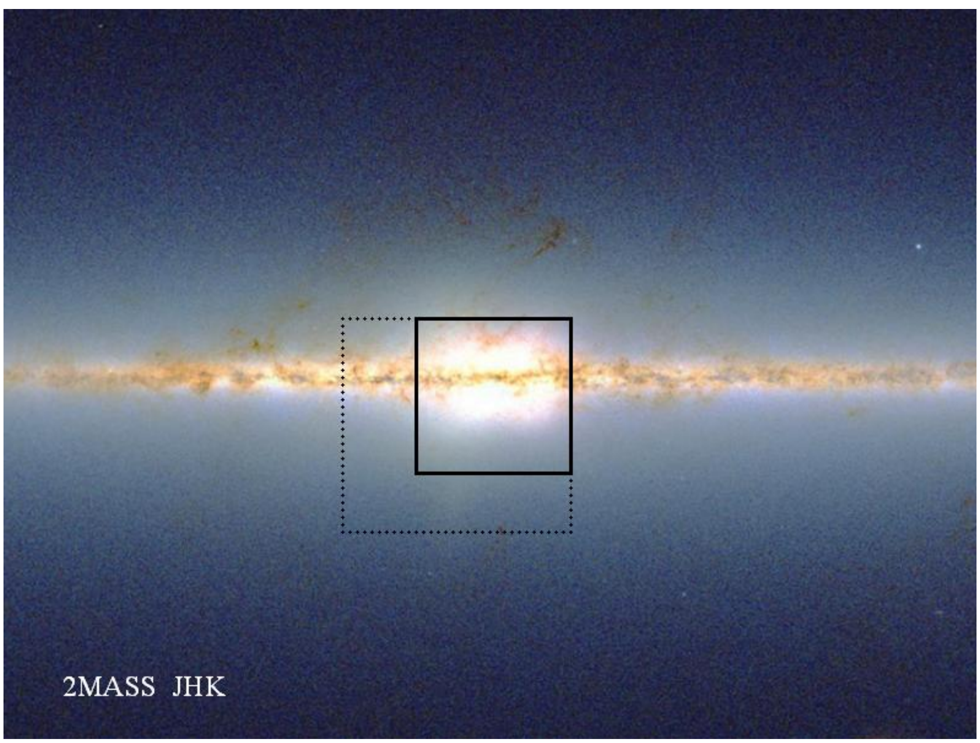

Figure 1: Central portion of the MW bulge from the 2MASS all sky JHK maps, showing the proposed VVV survey area of $20^0 \times 18^0$, between $-10^0 < L < 10^0$ and $-11^0 < B < 7^0$ (extended survey area also shown).

Most of the stars, gas and dust in the Milky Way are confined to the bulge and plane of the galaxy. Because of that, extinction and crowding make it difficult to unveil the inner structure of the Milky Way and to study in detail the formation and evolution of this representative galaxy. Traditional distance indicators have been used with varied success in the past. The approach was to concentrate in the clear ”windows”, where optical surveys can be carried out (MACHO, OGLE, etc). With the advent of VISTA, it is now possible to map the whole bulge systematically for several epochs in the $JHKs$ bands. We propose to cover a total of 360 sq deg (Figure 1), containing about 5×10^8 point sources. This unprecendented public survey will give the most complete catalog of variable objects in the bulge, with $\sim 10^6$ variables. Chief among them are the RR Lyrae, which are accurate primary distance indicators, being well understood from their chemical, pulsational and evolutionary properties. For the sake of space and coherence we concentrate on the RR Lyrae (goal 1 below), and the star clusters (goal 2 below), noting that similar worthy studies can be done for many of the other populations of variable objects (goals 3-10 below).

Existing, single epoch near IR surveys (e.g., COBE) have proven that the Galactic Bulge is boxy and contains a bar (Dwek et al. 1995, ApJ 445, 716). Presently, the only model we have for the formation of boxy/barred bulges is via secular evolution of a pre-existing disk. This scenario is believed to be the dominant channel of formation of bulges in late type spirals (Sbc), whereas early type spiral bulges (S0/Sa) show structural and kinematic evidence for an early, rapid collapse, which seems to be confirmed by the old age of their stellar population (see Kormendy & Kennicutt 2004 ARA&A, 42, 603).

However, the best studied spiral bulge, in the Milky Way, is precisely the most problematic one to understand in this context. While its surface brightness shows a barred structure, its stellar population is old (Kuijken & Rich 2002 AJ, 124, 2054, Zoccali et al. 2003 A&A, 399, 931) and it has α element enhancement, characteristic of a rapid formation. Most importantly, the chemical composition of bulge stars is different from that of both thin and thick disk stars (Zoccali et al 2006, submitted to Nature). Thus, the formation of the Milky Way bulge via secular evolution of the disk seems to be in contrast with the properties of its stellar population.

A large survey of the RR Lyrae in the bulge will allow us to map the 3-D structure of the bulge (unlike the single epoch surveys that can provide only 2-D maps) *and* will give us key information on the age of its population, given that RR Lyrae are tracers of the old population. This will allow us to make an important step forward in the solution of this puzzle. In the case of the bulge, the peak of their luminosity distribution defined the distance to the Galactic Center (Carney et al. 1995, AJ, 110, 1674). Now the peak and width of the distribution can be measured with care to determine the 3-D structure not only of the bulge, but also of the Sgr galaxy located behind the Milky Way (Alard 1996, ApJ, 458, L17).

At the same time, a comparison between the RR Lyrae (and type II Cepheids as well) in the field and in the globular clusters may hold precious information about the formation of the bulge. Modern ΛCDM cosmology predicts that large galaxies such as the Milky Way formed by accretion of hundreds of smaller “protogalactic fragments” perhaps not unlike its present-day dwarf spheroidal satellites (e.g. Altmann, Catelan & Zoccali 2005, A&A, 439, L5). Interestingly, two very massive globular clusters in the Galactic bulge, NGC 6388 and NGC 6441, have recently been suggested to be the remains of ancient dwarf galaxies that were accreted in the course of the Galaxy's history (Ree et al. 2002, ASP, 265, 101). These clusters might, in this sense, prove similar to the cases of M54, in the center of the Sagittarius dwarf spheroidal galaxy, which is currently been incorporated by the Milky Way (Ibata et al. 1995, MNRAS, 277, 781), and of ω Cen, which has long been suspected to be the remains of a dwarf galaxy (e.g. Abadi et al. 2003, ApJ, 591, 499).

Our proposed search for RR Lyrae and type II Cepheid stars in the Galactic bulge will reveal the presence of any debris related to the accretion events that might have led to the formation of the present-day NGC 6388 and NGC 6441. These globular clusters are both well known to contain extremely anomalous RR Lyrae populations, with periods that are much longer than those of known field RR Lyrae stars of similar high metallicity (e.g. Pritzl et al. 2000, ApJL, 530, L41, Pritzl et al. 2003, AJ, 126, 1381) In particular, the presence of the unusually long-period ($P > 0.45$ d) RRc (first overtone) variables, which have so far not been found in the general field but are present in large number in both these globular clusters (e.g. Catelan 2004, ASP, 310, 113), should provide the “smoking gun” for the presence of NGC 6388/NGC 6441-related debris in the general bulge field. In like vein, long-period RRab stars (fundamental pulsators) occupying the appropriate position in the period-amplitude diagram should also provide us with a strong indication of prior membership to such a protogalactic fragment.

2.2 Immediate objective:

The major VVV survey products will be a high resolution $JHKs$ color atlas of the whole Galactic bulge, and a catalog of bulge variable point sources, including positions, mean magnitudes, and amplitudes. This database would be public, a significant treasure for the whole community to exploit for a variety of scientific programmes. The top 10 scientific objectives of the VVV survey are:

1. To find RR Lyrae in the bulge, which will allow to: determine periods and amplitudes, measure accurate mean magnitudes, make the Bailey diagram, interpret the results of the variability analysis in terms of stellar pulsation and evolution models, and compare the pulsation properties of bulge variables with those of similar variables in the halo and nearby dwarf galaxies (e.g. Catelan 2006, astro-ph/0507464). The distances measured and RR Lyrae counts can be compared with the clump giants, which are excellent tracers of the inner bar (Stanek et al. 1994, ApJ, 429, L73). This would define the geometry of the inner bar and of additional structures (like a potential second bar - Nishiyama et al. 2006, ApJ, 621, L105), and explore the radial dependence of the density (e.g. Minniti et al. 1999, ASP, 165, 284), or trends with galactic latitude-longitude, to finally unveil the structure of the bulge. The microlensing surveys that we have been involved in (OGLE, MACHO) have discovered about 10% of the existing bulge RR Lyrae stars (e.g. Figure 2, see Alcock et al. 1998, ApJ, 492, 190, Udalski et al. 2002, Acta Astron., 52, 129). We estimate that our final survey will find more than 50% of the RR Lyrae throughout the whole bulge.

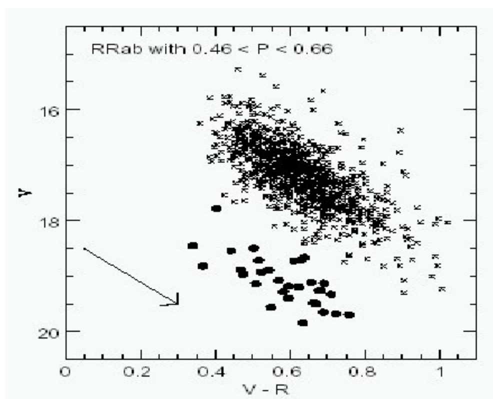

Figure 2: Optical color-magnitude diagram for bulge RRab (crosses), showing the sequence belonging to the Sgr dwarf galaxy (circles) located behind the bulge (Alcock et al. 1997, 474, 217). Differential reddening is very significant even in the bulge clear windows. The direction of the reddening arrow determines that the optical sample of RR Lyrae quickly becomes incomplete. There are about 2000 RR Lyrae known in the unreddened windows of the bulge, while the total population is estimated to be an order of magnitude larger than that.

2. To identify variable stars belonging to known star clusters. There are 40 globular clusters and 114 open clusters located in the VVV area (Figure 3), that would contain: RR Lyrae, type II Cepheids, Semiregulars, and EBs. Distances, reddenings, metallicities and HB types will be obtained for these clusters from an homogeneous dataset (e.g. Catelan et al. 2005, astro-ph/050963, Zoccali et al. 2003, A&A, 399, 931). In some favourable cases, ages can be measured. Table 1 at the end lists the globular clusters to be covered, giving positions in RA, DEC, galactic coordinates (L, B), and distances from the Sun. The asterisks in the last column indicate that one third of these clusters have uncertain distances. We will improve the distances for these globulars, and confirm the previous estimates for the rest of the open and globular clusters.

3. To find eclipsing binaries in large numbers. We roughly expect 5×10^5 binaries, an unprecedented database that will allow to: determine periods and amplitudes, accurate mean magnitudes, study stellar properties, and also select extrasolar planetary transit candidates. In particular, YY Gem like systems can be identified to constrain the lower main-sequence parameters (e.g. Torres & Ribas 2002, ApJ, 567, 1140), and the OGLE transit fields can be followed frequently to identify and measure extrasolar giant planets (e.g. Udalski et al.

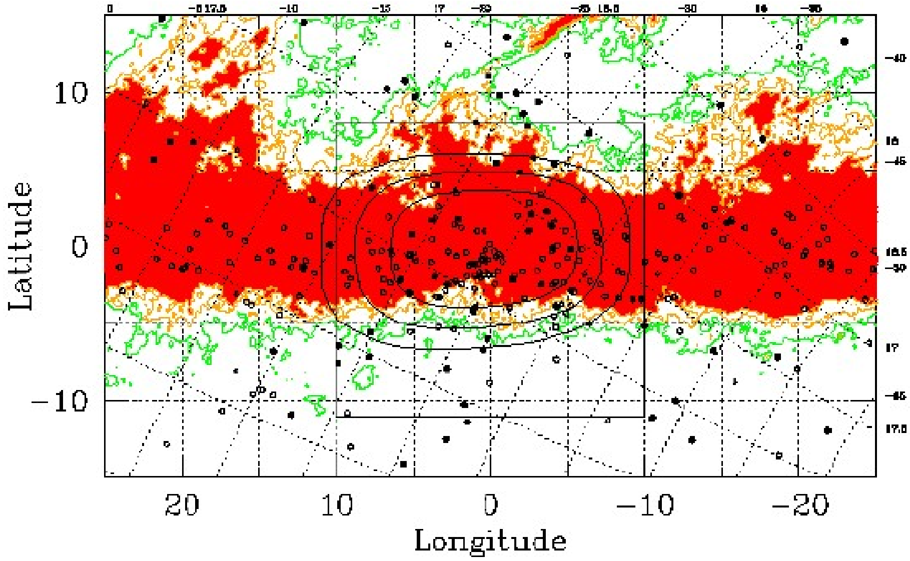

Figure 3: Map of the globular and open cluster positions (full and empty circles, respectively) towards the Milky Way bulge. Included in the VVV area are the 40 globular clusters listed in Table 1 (Harris 1996, AJ, 112, 1487), and 114 open clusters (Dias et al. 2006, A&A, 446, 949; Bica et al. 2003, A&A, 400, 533, and 2003, A&A, 404, 223). The bulge contours are indicated, as are the extinction contours of Schlegel et al. (1998, ApJ, 500, 525).

2002, Acta Astron. 52, 317).

4. To find rare variable sources. The massive variability dataset will allow us to search for: CVs (novae, dwarf novae) and other eruptive variables (e.g. RSCVn), eclipsing binary RR Lyrae in the bulge, eclipsing binary clump giants, binary microlensing events, etc (Figure 4). With the advent of Chandra, XMM, INTEGRAL, and the Cerenkov telescopes, a number of persistent and transient high energy sources have been discovered towards the inner Milky Way, with their locations pinpointed accurately (Aharonian et al. 2006, A&A, in press, Kuulkers et al. 2006, astro/ph0603130). We will also be able to identify the counterparts of high energy (X-ray and γ-ray) sources: accreting black holes, microquasars (e.g. Mirabel & Rodriguez 1998, Nature, 392, 673), binary pulsar companions, LMXBs, and HMXBs. In particular, this survey may finally reveal the still undetected counterparts of the most luminous persistent hard X-ray/jet sources in the Galactic Center region, 1E 1740.7-2942 (Mirabel et al. Nature 358, 215, 1992) and GRS 1758-258 (Rodriguez, Mirabel & Marti, ApJ 405, L15, 1992). A caveat is that although we would identify and monitor the counterparts of several variable high energy sources, we do not claim to be able to determine orbital periods for all XRBs counterparts given the sampling. However, the possibility of other time variable serendipity discoveries is open.

5. To search for microlensing events, specially: reddened events, short timescale events, and high magnification events in obscured high density fields. The spatial dependence of the microlensing optical depth has been modeled (Binney et al. 1997, MNRAS, 288, 365), and can probe directly the mass distribution contained in the inner regions. Unfortunately, current microlensing searches miss the regions where this optical depth is higher, poorly constraining these models (Bissantz & Gerhard 2002, MNRAS, 330, 591). In addition, we expect to detect microlensing of source stars in the Sgr dwarf galaxy (e.g. Popowski et al. 2005, ApJ, 631, 879).

6. To monitor the variability around the Galactic Center: an area of 1.5 sq deg around the Galactic Center will be the most frequently monitored field, for a total of 200 epochs spanning 5 years. Expected variability due to high magnification microlensing, or flares due to black hole accretion can arise (e.g. Chaname, et al. 2001, ApJ, 563, 793). The BH flares easily reach $K \sim 16$ mag, with a typical duration of 10-30 min. The expected flare

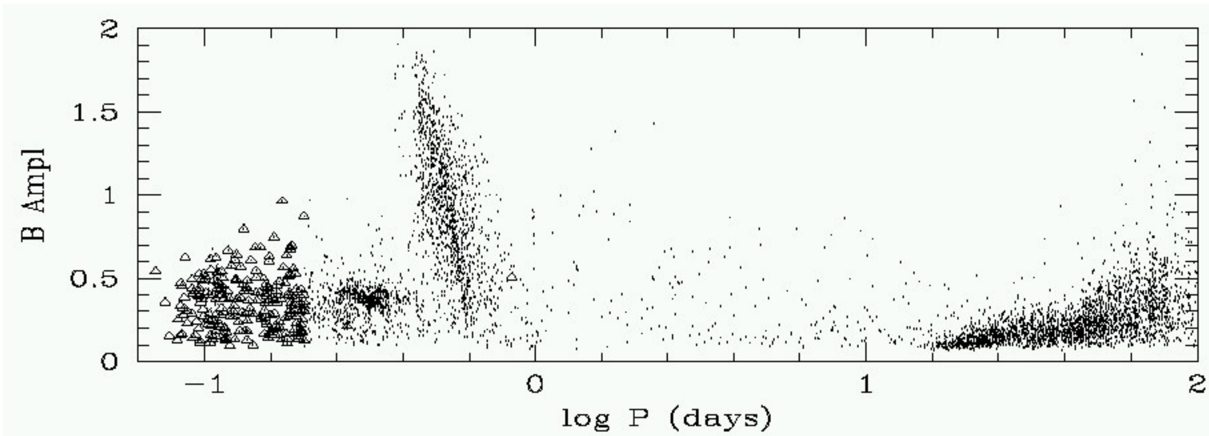

Figure 4: Optical period-amplitude diagram for pulsating bulge variables observed nightly. The IR period-amplitude diagram will be similar, but with smaller amplitudes ($\Delta K \sim 0.3\Delta V$), which on one hand makes detection harder, but on the other hand gives more accurate mean magnitudes and less sensitivity to reddening and metallicity effects. Note that it is possible to phase variables with periods of 0.1 day (triangles), that are an order of magnitude smaller than the sampling (1 day), provided that about 100 epochs are observed. This diagram allows the automatic classification of different types of variable stars: from left to right the groups seen are δScts, RRcs, RRabs, and Semiregular stars. Cepheids would be located in the empty regions with intermediate periods (few intervening disk Cepheids are expected). Variables showing aliasing problems (periods $1/n$ days or n days) were removed. Eclipsing binaries are also not plotted, they cover the whole range of periods and amplitudes in this diagram, but they can be discriminated based on the light curves and colors.

rate is 2-6 per day (Genzel et al. 2003, Nature, 425, 934; Eisenhauer et al. 2005, ApJ, 628, 246), in addition to a larger timescale variation predicted by the accretion simulations (Cuadra et al. 2006, MNRAS, in press). We also expect some Wolf Rayet variability in the population of massive stars and clusters in this region, and will search for eclipsing WR stars (e.g. Gamen & Niemela 2006, in preparation).

7. To search for new star clusters of different ages and identify their variable stars members, such as: Cepheids, Semiregulars, WUMas, and δSct. The asymmetric distribution of the known globulars in the Galactic Center region hints at a presence of about 10 undiscovered objects (Ivanov et al. 2005, A&A, 442, 195). Our team members have already carried out successful campaigns searching for new clusters in the 2MASS Point Source Catalog (Ivanov et al. 2002, A&A, 394, 1; Borissova et al. 2003, A&A, 411, 83, Bica et al. 2003, A&A, 408, 127). Note that 2MASS with a $K_{lim} = 14.5$ in the bulge discovered hundreds of open cluster candidates, plus two new globular clusters. Because we will reach 3-4 magnitudes deeper, we expect many new clusters. Having access to the images, we can improve our technique using a combination of: (i) search for peaks in the 2-dimensional histogram of the resolved point sources, and (ii) search for peaks in the unresolved flux. The distances and luminosities for the new clusters will be estimated.

8. To provide complementary IR color information (for reddening, temperatures, luminosities) and time coverage to the following past and on-going surveys: GLIMPSE-II and VST PHAS Hα survey (both limited to the Galactic plane), MACHO, OGLE, MOA, and PLANET. Near-IR counterparts and variability of interesting GLIMPSE-II and VST PHAS sources will be found. Also note the importance of the near-IR photometry for the microlensing events discovered by these microlensing surveys. For old events or new ones, our VVV survey will give field reddening and a baseline color and magnitude, that can immediately be translated to temperature and luminosity for the source star. The characterization of the source is essential for refining the microlensing light curve parameters and the lens physical properties (e.g. Beaulieu et al. 2006, Nature, 439, 437).

9. To find variable stars in the Sgr dwarf: Figure 2 shows that the Sgr RR Lyrae are well within reach and can be readily identified. RR Lyrae would give the 3-D structure of Sgr (e.g. Alard ApJ, 1996, 458, L17, Alcock et al. 1998, ApJ, 492, 190). In order to measure the depth and the tilt of Sgr along the line of sight, mean RR Lyrae magnitudes good to 0.01 mag are necessary. This can be achieved in the bulge fields provided enough epochs are observed. We will also detect and measure Miras, Semiregulars, and eclipsing binaries members of the Sgr dwarf galaxy (Cepheids are not expected).

10. To identify high proper motion objects and background QSOs: this last goal links the –seemingly unrelated– intrinsically faintest and brightest objects in the Universe. On the faint end we would use proper motions to find nearby late M-type stars, brown dwarfs (L and T types), and high velocity halo stars. The proper motions will probably turn up some of the most interesting low mass objects, and UKIDSS, DENIS and 2MASS will be used in some cases to extend the time baseline. On the intrinsically bright end, variability would also allow us to identify foreground quasars, providing an extragalactic reference scale for future proper motions (e.g. Piatek et al. 2005, AJ, 130, 95). QSOs have a relatively broad color range depending on their redshift, and their intrinsic variability increases monotonically with increasing time lags (de Vries et al, 2005 AJ, 129, 615), and amplitudes should be > 0.2 mag in the IR (Enya et al 2002 ApJS, 141, 45). We estimate that we will find > 500 AGN assuming a surface density of $2/deg^2$ with $K < 15.5$ (Leipski et al 2005 A&A, 440, L5) in the regions above and below the disk where $A_K < 0.5$ mags.

3 Are there ongoing or planned similar surveys? How will the proposed survey differ from those? (1 page max)

There is no similar large IR variability survey towards the Milky Way bulge. We have argued that this is a wonderful thing, then why it has not been done before? Because there were major problems, namely:

Extinction : large extinction and differential extinction, as shown in Figure 3 (Schlegel et al. 1998, ApJ, 500, 525). While this problem devastates optical surveys, confining them to pencil beam observations through "windows", it is alleviated in the near-IR. Color information from 3 different IR filters is mandatory in order to take the effect into account.

Crowding : decreases the effective magnitude limit. The photometry of 2MASS and DENIS was confusion limited in the bulge fields.

Aliasing : periods that are multiples of a day give aliasing. A short campaign is hardly sufficient to remove this, the microlensing surveys have demonstrated that a long campaign (as proposed here) is necessary.

Wide area : Technological difficulties in manufacturing large IR arrays and wide field IR imagers that are necessary to cover the entire Milky Way bulge repeatedly in a reasonable timescale.

VISTA now allows us to attack these problems systematically. It is a larger telescope than used by 2MASS, with a smaller duty cycle it can map a large area to deeper magnitudes. Short VISTA exposures in $JHKs$ pierce through the bulge, and the higher resolution represents a huge advantage in the crowded fields. The Besançon Galactic models allow to predict the stellar density, giving about 2×10^6 stars per square degree to $V = 20$ at Baade's window, one of the densest regions in the optical (e.g. Robin et al. 2003, A&A, 409, 523). To the limit of $Ks = 18$, we expect a similar number count, giving about one star per 25 pix^2. At the expected RR Lyrae magnitudes ($Ks = 15$), they will not be significantly affected in fields like that. The situation degrades for fields closer to the Galactic plane in the infrared, but for the densest regions even though incompleteness sets in at brighter magnitudes, we will use both the PSF fitting and the difference image analysis (DIA) method to detect variable point sources. A long term variability study is possible with a 5-yr long survey, adequately covering the baseline of long timescale microlensing events, and even permitting the detection of long term period changes in RR Lyrae. Even though there is no similar survey, there are several interesting ongoing and planned surveys that will provide complementary observations:

GALACTIC PLANE SURVEYS: UKIDSS-GPS: is mapping ±2 deg in Galactic latitude, but at a single epoch; VISTA GPS: proposes to map ±5 deg in Galactic latitude, but limited or no variability information, VPHAS: also only Galactic plane coverage in optical and Hα using the VST.

2MASS, DENIS: whole bulge coverage in the near-IR, single epoch, down to $K = 14.5$ in the bulge (Figure 1).

GLIMPSE-II: mid-IR, only Galactic plane coverage. This is a particularly interesting 150 hr SPITZER program to image the central +/- 10 deg of the plane with IRAC. The main scientific goals are to determine the content and distribution of stars, the stellar populations, and interaction of the strong nuclear wind with the ambient ISM above and below the nucleus, and the rate and location of current star formation in the inner Galaxy. The program is a fully sampled, unbiased, confusion-limited survey in all 4 IRAC bands. Even though it does not cover the whole bulge, we would give complementary variability information in the overlap region.

MICROLENSING SURVEYS: MACHO: optical V and R bands (limited color information, limited in regions with high extinction); OGLE: optical I band (no color information, limited in regions with high extinction)

ASTRO-F: All-sky survey satellite (far IR, poor resolution). This spacecraft is a 68.5-cm telescope with 2 instruments covering 6 bands from 2 to 180 μm in 13 bands. The survey will be 7-8$\times$ deeper than IRAS and MSX.

INTEGRAL: Survey of the whole Galactic bulge for high energy sources (Kuulkers et al. 2006, astro/ph0603130).

CHANDRA: The Chandra Multiwavelength Plane (ChaMPlane) Survey is a project to identify a large sample of serendipitous X-ray sources located to arcsec precision in deep ($>$ 20 ksec) Galactic center and plane fields ($-10^0 < B < 10^0$) imaged by the Chandra X-ray Observatory, including CVs, quiescent LMXBs, Be X-ray binaries, and stellar coronal sources. ChaMPlane includes an NOAO long-term VRIHα imaging survey (5 year, 30 nights total). This would likely miss sources located in regions of high extinction.

4 Observing strategy: (1 page max)

The strategy devised here allows to deliver interesting data to the community, enabling follow-ups throughout the survey:

- cover the whole bulge in $JHKs$ to 3-4 magnitudes deeper than 2MASS in the first season

- find the first variable point sources in the second season

- classify variable stars, microlenses, etc, and measure their amplitudes and periods in the third season

- refine the variable star parameters (improving periods, removing aliases, etc) for the optimal fields in the fourth and fifth seasons

- obtain final measurements based on light curves with 50-200 epochs for a large subset of the initial variables, and high proper motion objects at the end of the survey

In order to cover the bulge between $-10^0 < L < 10^0$ and $-11^0 < B < 7^0$, we ask for a grand total of 95 nights over 5 years: 5 nights the 1st year, 6 nights the 2nd year, 72 nights the 3rd year, 6 nights the 4th year, and 6 nights the 5th year. This accounts for a bit more than half of the Chilean guaranteed time over the period of 5 years; this is designed in order to leave place for another similar Chilean survey for 2007-2011. However, if no other Chilean survey is submitted, we ask for 175 nights total in order to double the survey coverage.

The final survey will cover 360 square degrees in the Galactic bulge. During the first year (2007) this whole area will be observed once in J during the first night, once in H during the second night, and three times in Ks, during the third, fourth and fifth night. Using only one filter per night maximizes returns, allowing to cover the whole area, yielding a deep $JHKs$ map of the whole bulge. Being fully aware of the confusion and background limits, the observing plan would circle alternatively through fields of varying density for optimal sky subtraction.

The second year (2008) each field will be observed once per night in Ks, for a period of 6 nights. The observing strategy is designed to cover 360 sq deg per night, with the observing efficiency 25% of the time. While it is preferable to observe contiguous full nights, the observing strategy can in principle be coordinated with another survey in order to use half nights for the first year. In that way the whole bulge is observed the second year, allowing the identification of variable sources (but not the phasing). These data will also allow the creation of deeper master maps in Ks, in order to fine tune the strategy for the main campaign of the following year.

The main variability campaign is carried out during 72 nights in the third year (2009). We ask for consecutive nights on this season, although in practice there will be a few holes due to weather and to the unfortunate fact that 2-3 nights per month are useless because the Moon transits in front of the bulge. We will use the J-band to map the whole bulge over and over. A subset of the fields can be observed more frequently (4 or 8 times per night). This strategy allows to partly remove aliasing and to improve the periods, while being more sensitive to smaller timescale variables and microlensing events. Also a subset of the fields can be observed in the Ks band. This is particularly important to discriminate RR Lyrae type c from short period contact binaries in cases where the light curves are not optimally sampled. The specific filter to use for the variability search planned for 2009 (year 3) can be J or Ks. On one hand, the J-band gives better photometric precision, higher RR Lyr amplitudes ($\Delta J \sim 1.5 \Delta K$), and deeper magnitudes. On the other hand, the Ks-band filter permits more coverage in heavily reddened regions, and gives tighter PSFs, on average by 0.1" arcsec, which would make a difference in the crowded regions. We adopt the J filter for this proposal, noting that we would optimize the strategy after the first year's JHK data is in hand and proper realistic simulations can be made on the different fields.

The fourth and fifth years (2010-2011) we will observe selected bulge fields in Ks for 6 nights per year, but with observations spread over the season. We plan to cover an area of 32 sq deg for 1 hour per day during 60 days. This allows the measurement of longer timescale variables, and the search for high proper motion objects.

5 Estimated observing time:

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P79	50	17:00–19:00 h	any	0.8	clear
P81	60	17:00–19:00 h	any	0.8	clear
P83	720	17:00–19:00 h	any	any	thin
P85	60	17:00–19:00 h	any	any	thin
P87	60	17:00–19:00 h	any	any	thin

5.1 Time justification: (1 page max)

POPULATION	$A_V = 0$ $A_J = 0$ $A_K = 0$ E(B-V)=0	$A_V = 1.5$ $A_J = 0.4$ $A_K = 0.2$ E(B-V)=0.5	$A_V = 5.0$ $A_J = 1.4$ $A_K = 0.6$ E(B-V)=1.5	$A_V = 10.0$ $A_J = 2.8$ $A_K = 1.1$ E(B-V)=3.2	$A_V = 15.0$ $A_J = 4.2$ $A_K = 1.7$ E(B-V)=4.8
Bulge RGB tip	K=8.0*	K=8.5*	K=9.5*	K=11.0	K=13.0
Sgr RGB tip	K=10.5	K=11.0	K=12.0	K=13.5	K=15.0
Bulge RGB Clump	K=12.9	K=13.4	K=14.4	K=15.9	K=17.9
Bulge RR Lyrae	K=14.3	K=14.9	K=15.9	K=17.3	K=19.3*
Sgr RGB Clump	K=15.4	K=15.9	K=16.9	K=18.4*	K=20.4*
Sgr RR Lyrae	K=16.8	K=17.3	K=18.3*	K=19.8*	K=21.8*
Bulge MS TO	K=17.0	K=17.5	K=18.5*	K=20.0*	K=22.0*
* = beyond detection					

The area covered in the bulge will be $20^0 \times 18^0$, between $-10^0 < L < 10^0$ and $-11^0 < B < 7^0$. Each field will be observed in the Ks-band with DIT=3 sec, NDIT=3, Njitter=2, Npaw=6. This gives a full 1.5×1.0 sq deg field covered every 170 sec, down to a magnitude of $Ks = 18$ at $S/N = 3$ for each object. For the J we will follow a similar strategy with DIT=5 sec, NDIT=2, Njitter=2, Npaw=6. This strategy yields about 32 sq deg per hour, or 360 degrees per night. The nights in June-July are long, and no major overheads are expected due to the simplicity of the program. The combined epochs will reach $J = 21.5$, $Ks = 20$, which is three magnitudes fainter than the unreddened bulge main sequence turn off, although the densest fields will be confusion limited. However, applying both PSF fitting and differential imaging (DIA) we will recover the light curves of most objects down to $J = 19.5$, $Ks = 18$ even in moderately crowded fields. This is more than 3 mag fainter than the unreddened RR Lyrae at the Galactic bulge. We expect to find RR Lyrae even in fields with $A_V = 10$ mag.

The table above lists some reference Ks-band magnitudes at the distance of the bulge for a range of extinction and reddening values. These typical magnitudes were obtained from Carney et al. (1995, AJ, 110, 1674), Alard (1996, ApJ, 1996, 458, L17), Alcock et al. (1998, ApJ, 492, 190), Zoccali et al. (2003, A&A, 399, 931). As a reference point, for Baade's window $E(B-V) = 0.5$ mag, then $A_V = 1.5$ mag, $A_J = 0.4$, and $A_K = 0.2$ mag (Rieke & Lebofsky 1985, ApJ, 288, 618).

This table shows that for the tip of the bulge RGB, for the RGB clump giants, and even for the tip of the Sgr galaxy RGB, the VVV survey will be able to see giants throughout the bulge, even in the most obscured regions. The bulge RR Lyrae and the Sgr galaxy clump giants will fade beyond detection for the regions with highest extinction ($A_V > 10$) at low Galactic latitudes. Finally, the RR Lyrae of the Sgr galaxy and the bulge main sequence turn-off will be detected only in the regions with low absorption ($A_V < 2$) at higher latitudes.

Bright point sources with $Ks < 10.0$ will be saturated in the individual images. Thus, most unreddened bulge Mira variables will be saturated, but Miras in the Sgr dwarf galaxy can be monitored, as well as Miras located in regions with very high extinction. In addition, bright star saturation, persistence effects and cross talk may be an issue (e.g. Dye et al. 2006, in preparation), but we estimate than in the worst fields only a small portion of the field would be rendered useless. For example, in the optical microlensing surveys where CCD bleeding is comparatively worse, less than 5% of the most crowded bulge fields is lost.

Illustrations of accurate crowded field IR photometry are shown in Figure 5. The left panel shows NTT + SOFI photometry of the transit of the extrasolar planet OGLE-TR-113, which has a mean magnitude $Ks = 13.5$ and a depth of transit of $A_K = 0.03$ mag. The right panel shows NTT+SOFI photometric errors as function of magnitude for J and Ks.

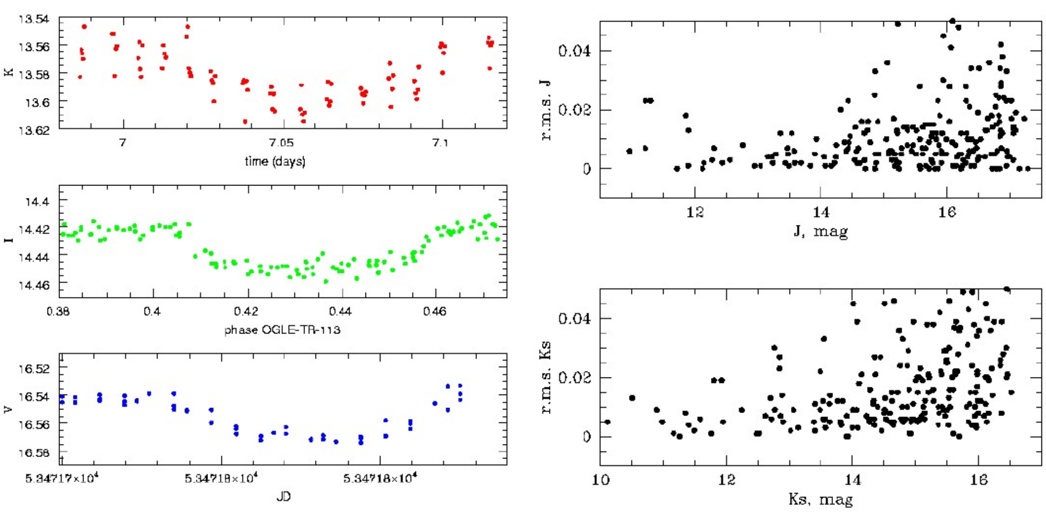

Figure 5: LEFT: Light curve of star OGLE-TR-113 during a planetary transit with amplitude $\Delta K = \Delta I = \Delta V = 0.03$ mag, as measured with VLT + VIMOS in the V-band by us (bottom), by OGLE in the I-band (middle), and with NTT + SOFI by us (top). This star is located right on the Galactic plane in the Carina field, a moderately crowded region. The NTT + SOFI observations were acquired with a similar strategy as proposed here. This Ks-band light curve with $rms < 0.01$ mag illustrates the quality of photometry possible with VISTA for the VVV survey. RIGHT: Accuracy of the relative photometry that we have obtained with SOFI as a function of magnitude. The total integration time was 30 sec, and the limiting magnitudes are 2 mags fainter. The magnitudes and the r.m.s. are calculated with two iterations, removing the $> 10\sigma$ outliers.

6 Data management plan: (3 pages max)

6.1 Team members:

Name	Function	Affiliation	Country
Dante Minniti	PI, photometry, light curves	University Catolica	RCH
Manuela Zoccali	Photometry, analysis	University Catolica	RCH
Marcio Catelan	Theory, photometry, light curves	University Catolica	RCH
Lorenzo Morelli	Astrometry, light curves	University Catolica	RCH
Claus Tappert	Photometry, light curves	University Catolica	RCH
Giulian Pignata	Pipeline, astrometry	University Catolica	RCH
Maria Teresa Ruiz	Astrometry, photometry	University of Chile	RCH
Giovanni Carraro	Astrometry, photometry	University of Chile	RCH
Rodolfo Barba	Reductions, Pipeline	University of La Serena	RCH
Roberto Gamen	Reductions, Pipeline	University of La Serena	RCH
Wolfgang Gieren	Photometry, light curves	University of Concepcion	RCH
Douglas Geisler	Photometry, analysis	University of Concepcion	RCH
Grzegorz Pietrzynski	Photometry, astrometry, light curves	University of Concepcion	RCH
Ronald Mennickent	Photometry, astrometry, light curves	University of Concepcion	RCH
Radostin Kurtev	Reductions, pipeline	University of Valparaiso	RCH
Felix Mirabel	Photometry, analysis	European Southern Observatory	ESO
Valentin Ivanov	OB Preparation, Data Quality Control III	European Southern Observatory	ESO
Jordanka Borissova	OB Preparation, photometry, light curves	European Southern Observatory	ESO
Ivo Saviane	Reductions, Pipeline	European Southern Observatory	ESO
Lorenzo Monaco	Reductions, Pipeline	European Southern Observatory	ESO
Marina Rejkuba	Simulations, light curves	European Southern Observatory	ESO
Maria Messineo	Simulations, light curves	European Southern Observatory	ESO
Beatriz Barbuy	Photometry, analysis	University of Sao Paulo	Other
Leandro Kerber	Pipeline, photometry	University of Sao Paulo	Other
Eduardo Bica	Photometry, analysis	University of Porto Alegre	Other
Andrew Stephens	Simulations, photometry	Hawaii	USA
Juan Jose Claria	Photometry, analysis	University of Cordoba	Other
Andrea Ahumada	Pipeline, photometry	University of Cordoba	Other
Jim Emerson	VDFS Coordinator	Queen Mary University of London	UK
CASU (VDFS) team	Pipeline Processing	University of Cambridge	UK
CASU (VDFS) team	Data Quality Control I	University of Cambridge	UK
WFAU (VDFS) team	Data Quality Control II	University of Edinburgh	UK
WFAU (VDFS)	Science archive	University of Edinburgh	UK

6.2 Detailed responsibilities of the team:

We will use the VISTA Data Flow System (VDFS; Emerson et al. 2004, SPIE, 5493, 401; Irwin et al. 2004, SPIE, 5493, 411; Hambly et al. 2004, SPIE, 5493, 423) for all aspects of data management, including: pipeline processing and management; delivery of agreed data products to the ESO Science Archive; production of a purpose-built IVOA compliant science archive with advanced datamining services; enhanced data products including federation of VISTA survey products with SDSS survey products. Standardised agreed data products produced by VDFS will be delivered to ESO, with a copy remaining at the Science Archive in Edinburgh.

The VDFS is a collaboration between the UK Wide Field Astronomy Units at Edinburgh (WFAU) and Cambridge (CASU) coordinated by the VISTA PI (QMUL) and funded for VISTA by PPARC. The VDFS is a working systems-engineered system that is already being successfully employed for the UKIRT WFCAM surveys as a test bed for the VISTA infrared surveys, and which is sufficiently flexible as to be applicable to any imaging survey project requiring an end-to-end (instrument to end-user) data management system. We enphasise the track record over the last decade of both the Cambridge and Edinburgh survey units in processing and delivering large-scale imaging datasets to the community as exemplified by the WFCAM Early Data release (EDR, (*http://surveys.roe.ac.uk/wsa/dboverview.html*) Lawrence et al 2006 and Dye et al 2006, in preparation).

In addition to the UK VDFS, the VVV survey team involves astronomers of Chilean institutions, and of the European Southern Observatory based at Vitacura. Our Chilean team includes experienced members from the microlensing surveys (OGLE, MACHO), as well as staff ESO members experienced in all aspects of IR imaging and instrumentation. We have capable people in charge of the data reduction, pipeline, photometry, astrometry, database, light curves, and simulations.

DM will manage and be involved in all aspects of the project for Chile, VI for ESO Vitacura, and JE for the VDFS. MZ and MC will aid deciding the data taking strategy and scientific priorities. VI and RB will lead the OBs preparations efforts, aided by RG, JB, IS, LM, RK, GC. All members of the collaboration will be involved in the photometry led by GP and DG (both PSF fitting photometry and DIA photometry), and will support MR, AS, MM in making the Monte-Carlo simulations to compute detailed photometric and sampling efficiencies. The astrometry will be carried out by GC, LM and MTR. RM and WG will decide on variability and phasing criteria, along with AA, JJC, BB, FM. LM and EB will take charge of creating the variability catalog, including LK, GC, CT, AS, CP, GB.

6.3 Data reduction plan:

VISTA will produce about 1 Tb of data per night for our survey, larger than the nominal average because of the short exposures. Longer exposures are not useful because the limitation is crowding and the number of saturated stars will increase. For us the first two years of the survey represent the steeper effort in terms of manpower and resources. The data reduction will be using the VDFS, operated by the VDFS team, and augmented by Chilean and ESO scientists, especially for product definition and product Quality Control. We divide the plan into three distinct but intimately related parts: pipeline processing, science archiving, and variability search.

Pipeline processing:

The Cambridge Astronomy Survey Unit (CASU) are responsible for the VDFS pipeline processing component which has been designed for VISTA and scientifically verified by processing wide field mosaic imaging data from UKIRT's NIR mosaic camera WFCAM and is now routinely being used to process data from the WFCAM at a rate of up to 250GB/night. It has also been used to process ESO ISAAC data e.g. the FIRES survey data and a range of CCD mosaic cameras. The pipeline includes the following processing steps but is a modular design so that extra steps are easily added. All the steps will have been tested on a range of input VISTA datasets, and include: instrumental signature removal – bias, non-linearity, dark, flat, fringe, cross-talk; sky background tracking and removal during image stacking – possible need to also remove other 2D background variations from imperfect multi-sector operation of detectors; define and produce a strategy for dealing with image persistence from preceding exposures; combine frames if part of an observed dither sequence or tile pattern; consistent internal photometric calibration to put observations on an approximately uniform system; basic catalogue generation including astrometric, photometric, shape and Data Quality Control (DQC) information; final astrometric calibration from the catalogue with an appropriate and World Coordinate System (WCS) in all FITS headers; basic photometric calibration from catalogue using suitable pre-selected standard areas covering entire field-of-view to monitor and control systematics; each frame and catalogue supplied with provisional calibration information and overall morphological classification embedded in FITS files; propagation of error arrays and use of confidence maps; realistic errors on selected derived parameters; nightly extinction measurements in relevant passbands; pipeline software version control – version used recorded in FITS header; processing history including calibration files recorded in FITS header.

Science archiving:

The concept of the science archive (SA, see Hambly et al. 2004, SPIE, 5493, 423) is key to the successful exploitation of wide field imaging survey datasets. The SA ingests the products of pipeline processing (instrumentally corrected images, derived source catalogues, and all associated metadata) into a database and then goes on to curate them to produce enhanced database-driven products. In the VDFS science archive, the curation process includes, but is not limited to, the following: individual passband frame association; source association to provide multi-colour, multi-epoch source lists; global photometric calibration; enhanced astrometry including derivation of proper motions; consistent list-driven photometry across sets of frames in the same area; cross-association with external catalogues; and generation of new image products, e.g. stacks, mosaics and difference images etc., all according to prescriptions set up for our VVV survey. All these features are available in the context of a continually updating survey dataset from which periodic releases (as required by the community) can be made. Moreover, end-user interfaces were catered for from the beginning in the VDFS design process, and the philosophy has always been to provide both simple and sophisticated interfaces for the data. The former is achieved via simple point-and-click web forms, while the latter is achieved via exposing the full power of the DBMS back-end to the user. To that end, full access to Structure Query Language and the relational organization of all data are given to the user. We have developed a generalized relational model for survey catalogue data in the VDFS. The key features to note are the normalized design with merged multi-waveband catalogue data (the table of most use for scientific queries) being part of a related set of tables that allow the user to track right back to the individual source images if they require to do so; and also that the merged source tables (as derived either from individually analyzed images, or consistently across the full passband set available in any one field) are seamless, and present the user with a generally applicable science-ready dataset. Similar relational models describe the organization of all data in the science archive (image, catalogue, calibration metadata, etc. - see Hambly et al. 2004, SPIE, 5493, 423). The relational model is applicable to any imaging survey project, and provides an easy-to-use science-ready data resource for the community scientist in the form of a seamless, merged multi-colour multi-epoch source catalogue. The science archive has a high-speed query interface, links to analysis tools such as TopCat, and advanced new VO services such as MySpace. Data products are being successfully ingested into the WFCAM Science Archive (WSA) in Edinburgh, with the EDR in Feb 2006, and the WSA concept was also demonstrated on the SuperCOSMOS Science Archive (SSA). *http://surveys.roe.ac.uk/ssa/* Ours is intrinsically a multi-wavelength project and most science will come from the linking of VISTA data with other large catalogs, and the WSA is designed to enable such links.

Variability:

The first year will cover 360 sq deg in the bulge in $JHKs$. Using the initial photometry in these fields, we will be able to fine tune the cuts that automatically flag variables to produce the catalog of variable sources, that could be then integrated to the VDFS for the rest of the programme. The variability catalog will be made in Chile, where we we count with a Beowulf cluster, and similar equipment is available in Brazil and Argentina. The data for the first two years is manageable, but we plan to expand the capabilities and storage space for the third year, when the most intense campaign is carried out. The renovation of our national Astronomy Project FONDAP will provide the resources. The final bulge light curves will have 50 to 200 epochs, depending on the location, as some fields will be monitored more frequently (e.g. the Galactic Center and OGLE transit fields). Phasing the light curves of $\sim 5 \times 10^8$ point sources to find $\sim 10^6$ variables will not be a minor task. The large number of epochs requested will aid in discriminating different variable star populations, determining accurate ephemeris for periodic variables and securing completeness of the samples (see Figure 4). A big related task that must not be underestimated are the Monte-Carlo simulations to determine the survey efficiency. We envisage two strong dependences: photometric efficiency, and sampling efficiency. The photometric efficiency has to be modeled on a field by field basis, as the limiting magnitudes and crowding vary widely across the bulge. The sampling efficiency will also depend on the field, but must take into account the models of variables with different light curves.

6.4 Expected data products:

– Instrumentally corrected frames (pawprints, tiles etc) along with header descriptors propagated from the instrument and processing steps (science frames and calibration frames)
– Statistical confidence maps for each frame
– Derived catalogues (source detections from science frames with standard isophotal parameters, model profile fitted parameters, image classification, etc.)
– Data Quality Control database
– Database-driven image products (stacks, mosaics, difference images, image cut-outs)
– Frame associations yielding a survey field system; seamless, merged, multi-colour, multi-epoch source catalogues with global photometric calibration, proper motions
– Source remeasurement parameters from consistent list-driven photometry across all bands in any field
– Catalog of bulge variable point sources, including positions, mean magnitudes, and amplitudes.

6.5 General schedule of the project:

We expect the yearly release of science products at about 6-9 months after the observations. The timeline is:

• FIRST YEAR: – observations of 360 sq deg in $JHKs$; – image pipeline basic reductions; – image tiling and combination to produce the first $JHKs$ atlas ; – photometric measurements for the individual epochs; – establishment of criteria for automatic detection of variability; – photometric efficiency Monte-Carlo simulations.

• SECOND YEAR: – observations of 360 sq deg, 6 epochs in Ks; – image pipeline basic reductions; – photometric measurements for the individual epochs; – search for variable point sources (PSF fitting and difference image analysis).

• THIRD YEAR: – observations of 360 sq deg, 72 epochs in J; – image pipeline basic reductions; – photometric measurements for the individual epochs; – search for variable point sources (difference image analysis); – phasing the light curves; – catalogue of variables made.

• FOURTH YEAR: – observations of 32 sq deg, 60 epochs in Ks; – image pipeline basic reductions; – photometric measurements for the individual epochs.

• FIFTH YEAR: – observations of 32 sq deg, 60 epochs in Ks; – image pipeline basic reductions; – photometric measurements for the individual epochs; – re-phasing of light curves; – sampling efficiency Monte-Carlo simulations; – final catalogue of variables ; – image tiling to produce deep Ks-band maps of the whole bulge; – astrometry and identification of high proper motion objects.

7 Envisaged follow-up: (1 page max)

In Chile we have access to a variety of facilities for follow-up of the VVV survey that our team members are interested in. An interesting point is that some of the follow-up observations can be carried out early, before the completion of the whole survey. The most straightforward examples are listed below, where only current capabilities are mentioned. In addition to this current instrumentation, we will have access to the second generation instruments at VLT, GEMINI and MAGELLAN, and we also expect our VVV survey to feed interesting targets to ALMA and the giant 25-100 m ground based telescopes.

• RR Lyrae:

Our high priority follow-up project would be the kinematics and chemical abundances of bulge RR Lyrae with FLAMES at the VLT and MIKE-Fibers at Magellan.

• Microlensing Events:

Spectroscopy with a moderate size telescope needed for the full characterization of the source star (EMMI at the NTT or Goodman spectrograph at SOAR). In the special parallax events, follow up with a space telescope (refurbished HST) might allow the detection of the lens directly.

• Transit candidates:

Extrasolar planetary transit candidates need to be followed up spectroscopically, either with UVES at the VLT or MIKE at Magellan.

• Galactic Center:

Flares or lensing might be followed up with high resolution imaging and spectroscopy with NACO and SINFONI at the VLT in Rapid Response Mode.

• New cluster candidates:

Deep imaging and spectroscopy, likely in the IR (e.g. with SOFI at the NTT), in order to determine the distances and total masses. For the massive star clusters and star forming regions in the galactic center region, NACO will be more appropriate.

•Eclipsing binaries:

Suitable interesting targets would be observed spectroscopically (Echelle at the du Pont, FEROS or EMMI at the NTT) in order to obtain Keplerian masses.

•CVs and pre-CVs:

Optical spectroscopy with NTT+EMMI to confirm the classification and for confirmed CVs additional time-resolved spectroscopy to measure the orbital periods. In the case of pre-CVs this will also yield white-dwarf parameters ($T_{\rm eff}$, $\log g$) and the spectral type of the red dwarf.

• High proper motion objects:

Imaging in subsequent years to refine the proper motion measurements (with SOFI at the NTT), and spectroscopy for spectral typing of late M stars and Brown Dwarfs, or radial velocities to obtain the orbital parameters around the Galaxy for high velocity halo stars (e.g. with FORS at the VLT).

• QSOs:

Variability selected background quasars and AGN need to be confirmed spectroscopically with FORS at the VLT or GMOS at GEMINI-S in order to determine class and redshift. They will provide an absolute frame for astrometric purposes.

8 Other remarks, if any: (1 page max)

We are willing and able to complement other proposed public VISTA surveys. Our strategy has been designed to cover the maximum area without loss of scientific objectives, and time flexibility as much as possible, but could be redesigned to acommodate additional goals suggested by the PSP.

However, there are some key issues that we would like to stress:

Data homogeneity is important: given the huge bulge stellar density gradient and nonuniform interstellar absorption, the casual reader will immediately be tempted to define an observing strategy that changes from field to field. However, this has catastrophic impact in a massive variability search.

Areal completeness is important: we need to map the whole bulge. Only this will allow the definitive analysis of the spatial distributions (structure, gradients), and comparisons of the different populations in situ. Pencil beam surveys have been very useful insofar as a whole scale map is available for calibration.

Time completeness is important: we need light curves with 50-200 epochs, obtained with the proposed time spacing, through several years. Otherwise our light curves will not allow detailed pulsation studies (e.g. double mode RR Lyrae), aliasing will plague the data, and in general the determination of physical parameters for the different populations of variable objects will suffer.

Scheduling is important: during the main variability campaign to be carried out in year 3 we need observations using consecutive nights centered in the bulge season. About 2.5 months centered in June 2009 need to be blocked for the VVV survey. We leave the scheduling of the first two years totally flexible, while the last two years we only require on hour per night over a period of two months.

Chilean time is important: We ask for a grand total of 95 nights over 5 years for this VVV survey covering 360 sq deg on the Milky Way bulge, accounting for about half of the Chilean time over that period, in order to allow the observations for any other similar Chilean proposal. This is clearly a national effort: we are a collaboration that involves scientists (faculty) from all national astronomical institutions (Univ. de Chile, Univ. Catolica, Univ. de Concepcion, Univ. de La Serena and Univ. de Valparaiso). Our VVV survey strengthens the ties and collaborations with Europe thanks to the heavy involvement of staff members from ESO Vitacura and UK VDFS: this is a joint effort, that even goes beyond, reaching colleagues in Argentina and Brazil.

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P79	100	17:00–19:00 h	any	0.8	clear
P81	120	17:00–19:00 h	any	0.8	clear
P83	720	17:00–19:00 h	any	any	thin
P85	120	17:00–19:00 h	any	any	thin
P87	690	17:00–19:00 h	any	any	thin

Therefore, we would like to stress again that if no other Chilean survey is carried out, we expand our request to 175 nights total over the next 5 years, in order to extend the coverage of this VVV survey to 600 sq deg on the bulge, covering $-10^0 < L < 20^0$, $-17^0 < B < 7^0$. In that scenario, we would request 10 nights in the first year, 12 nights in the second year, 72 consecutive nights in the third year, 12 nights in the fourth year, and 69 nights in the last year, as detailed in the Table above. The top ten scientific objectives are still valid in this expanded proposal, which in addition would allow to extend our map to the inner halo and inner disk populations, and to the core of the Sgr dwarf galaxy (Fig. 1, with the extended area shown in dotted lines).

	TABLE 1					
IDName	RA	DEC	L	B	$D(kpc)$	
NGC6266	17 01 12.8	-30 06 49	353.57	7.32	6.9	
NGC6293	17 10 10.2	-26 34 55	357.62	7.83	8.8	
NGC6304	17 14 32.1	-29 27 44	355.83	5.38	6.0	
NGC6316	17 16 37.3	-28 08 24	357.18	5.76	11.0	
NGC6325	17 17 59.2	-23 45 57	0.97	8.00	8.0	
NGC6355	17 23 58.6	-26 21 13	359.58	5.43	9.5	
Terzan2	17 27 33.1	-30 48 08	356.32	2.30	8.7	
Terzan4	17 30 39.0	-31 35 44	356.02	1.31	9.1	*
HP1	17 31 05.2	-29 58 54	357.42	2.12	14.1	*
Liller1	17 33 24.5	-33 23 20	354.84	-0.16	9.6	*
NGC6380	17 34 28.0	-39 04 09	350.18	-3.42	10.7	
Terzan1	17 35 47.2	-30 28 54	357.56	0.99	5.6	
Ton2	17 36 10.5	-38 33 12	350.80	-3.42	8.1	*
NGC6401	17 38 36.6	-23 54 34	3.45	3.98	10.5	
Pal6	17 43 42.2	-26 13 21	2.09	1.78	5.9	
Djorg1	17 47 28.3	-33 03 56	356.67	-2.48	12.0	*
Terzan5	17 48 04.9	-24 46 45	3.84	1.69	10.3	*
NGC6440	17 48 52.7	-20 21 37	7.73	3.80	8.4	
NGC6441	17 50 12.9	-37 03 05	353.53	-5.01	11.7	
Terzan6	17 50 46.4	-31 16 31	358.57	-2.16	9.5	*
NGC6453	17 50 51.7	-34 35 57	355.72	-3.87	9.6	
UKS1	17 54 27.2	-24 08 43	5.12	0.76	8.3	*
Terzan9	18 01 38.8	-26 50 23	3.60	-1.99	6.5	*
Djorg2	18 01 49.1	-27 49 33	2.76	-2.51	6.7	*
Terzan10	18 02 57.4	-26 04 00	4.42	-1.86	5.7	*
NGC6522	18 03 34.1	-30 02 02	1.02	-3.93	7.8	
NGC6528	18 04 49.6	-30 03 21	1.14	-4.17	7.9	
NGC6540	18 06 08.6	-27 45 55	3.29	-3.31	3.7	
NGC6544	18 07 20.6	-24 59 51	5.84	-2.20	2.7	
NGC6553	18 09 17.6	-25 54 31	5.25	-3.03	6.0	
2MS-GC02	18 09 36.5	-20 46 44	9.78	-0.62	4.0	*
NGC6558	18 10 17.6	-31 45 50	0.20	-6.02	7.4	
Terzan12	18 12 15.8	-22 44 31	8.36	-2.10	4.8	*
NGC6569	18 13 38.8	-31 49 37	0.48	-6.68	10.7	
NGC6624	18 23 40.5	-30 21 40	2.79	-7.91	7.9	
NGC6626	18 24 32.9	-24 52 12	7.80	-5.58	5.6	
NGC6638	18 30 56.1	-25 29 51	7.90	-7.15	9.6	
NGC6637	18 31 23.2	-32 20 53	1.72	-10.27	9.1	
NGC6642	18 31 54.1	-23 28 31	9.81	-6.44	8.4	
NGC6656	18 36 24.2	-23 54 12	9.89	-7.55	3.2	
* = uncertain distances						